AMERICAN SOCIETY OF CIVIL ENGINEERS.

INSTITUTED 1852.

TRANSACTIONS.

NOTE.—This Society is not responsible, as a body, for the facts and opinions advanced in any of its publications.

CLXII.

(Vol. VII.—June, 1878.)

THE SOUTH PASS JETTIES.

DESCRIPTIVE AND INCIDENTAL NOTES AND MEMORANDA.

By E. L. CORTHELL, C. E., Member of the Society.

Read at the Tenth Annual Convention, June 18th, 1878.

It is nearly three years since the construction of the jetties was commenced.

Two years ago, at the annual convention, we gave you in a very fragmentary manner, an account of the work, and of some of the results obtained at that time.

We propose now to deal somewhat more generally with the subject, and to supplement the descriptive statements with some memoranda incident to the work.

It will be remembered, in the discussion of the subject, that the jetties are still incomplete; that the results aimed at are not yet fully realized, and that many of the phenomena are the results of progressive

works, and are incidents simply of the process of channel making, at which the river has been set at work.

The subject is one which for importance and multiplicity of interesting details is worthy of a volume. In fact, nothing but a full, continuous history of the work, dealing with details as well as with general descriptions and results, can give one a clear idea of the magnitude of the work done, and of the extraordinary results accomplished in so short a time.

Three years ago, a vessel drawing seven feet had great difficulty in passing over this long flat bar of mud and sand. Now, for uniformity, width, depth and navigability, the channel is nearly as good as the Sandy Hook entrance to New York harbor.

Important in every point of view, and, as well known as the subject is, we approach it with no reluctance or hesitation, and boldly give all the actual facts relating to subjects about which there has been such a diversity of opinion among engineers, and in reference to which so many predictions of failure have been made,

We propose for arguments to give facts and results obtained by observations and surveys in which we have perfect confidence, and to take from our map case and note books whatever may relate to the subjects, and to draw from the facts of others when we have not had the opportunity to obtain them by personal observation.

First.—THE GENERAL REGIMEN OF THE RIVER AND PASSES.

The relation existing between the three passes is so intimate, that it will be necessary to consider them all, and the river itself, in order to understand all the forces at work, and to know how best to meet and to use these forces.

One mile above the head of the passes the Mississippi River is 8 000 feet wide, the approximate depth is 30 feet, the sectional area 240 000 square feet, and the discharge at the flood stage of the river is about 1 000 000 cubic feet per second. The slope of the flood surface of the river between the head of the passes and quarantine station, a distance of 37 miles, is about $\frac{3}{4}$ of an inch per mile, the slope of Southwest Pass and Pass à l'Outre is about 1 inch per mile, and that of South Pass about $1\frac{1}{2}$ inches per mile.

The banks are low and marshy, and are overflowed by the ordinary flood tide at high river.

The bed of the river, as well as of the passes, is alluvium, easily abraded and carried away by slight increase of current.

The regimen of the passes, as to sectional area and volume of discharge, is variable, and dependent upon several causes, viz.: the different rate of extension of the passes into the Gulf; the state of the tide; the prevalence of winds from certain directions; the growth and subsequent disappearance of mud lumps at the mouths of the passes, and local obstructions in the passes or in the main river immediately above.

On account of the soft nature of the alluvial bed over which the water flows, the equilibrium between sectional area, slope, velocity and volume is very easily disturbed, so that slight and almost inappreciable causes often produce important results. For instance, about four years ago the government dredge was moved from Southwest Pass bar to the bar at Pass à l'Outre. The immediate result was the shoaling up to its normal depth of the Southwest Pass bar, and the deepening on the other through a narrow channel from 12 to 18 feet. The more important result was the deepening and enlargement of the whole section of Pass à l'Outre, from the bar to the head of the passes.

Humphreys and Abbot give the following as the proportional discharge of each pass:

Southwest Pass, 46 per cent.

Pass à l'Outre or Northeast Pass, 46 per cent.

South Pass, 8 per cent.

In 1875 Maj. Howell found the following:

Southwest Pass, 39 per cent.

Pass à l'Outre, 51 per cent.

South Pass, 10 per cent.

Water is not the only element that flows to the sea through the Lower Mississippi and the passes. About one thousandth of the volume is sedimentary matter held in suspension by the current.

The presence of this element, and that, too, such a variable element, is the cause of many phenomena which considerably complicate the problem of the improvement of the pass and bar.

The conditions affecting the ratio and kind of sediment are various.

Each tributary discharges a different kind, and has a different ratio and weight. The ratio of sand to the whole quantity of sediment in suspension is the most important element, for on account of its weight it needs a strong current to carry it out to sea.

Then again, the size of the particles of sand affects the carrying power of the current.

All the facts that it is possible to obtain are being carefully collated from patient and thorough observation, by Capt. M. R. Brown, the U. S. inspecting officer stationed at the Jetties.

The following is the result of one full year's observations to ascertain the amount of sediment carried to sea through South Pass: Total amount, 27,555,900 cubic yards, and as South Pass is about one-tenth of the river, we can assume that the whole amount carried annually to the gulf, after passing Cubits Gap, is 275,559,000 cubic yards.

Second.—The Condition of the South Pass and Bar in 1875.

At the head of the passes a great middle ground shoal, extended from Southwest Pass to Pass à l'Outre, completely across the entrance to South Pass.

Over this shoal not more than 15 feet of water could be carried into the pass.

An island, with a secondary shoal above it, divided the waters flowing into the pass into two channels. Below this island the channel is uniform in depth and width, the latter being about 700 feet, and the former 40 feet, with an approximate sectional area of 23,000 square feet. The pass presents the appearance of a beautiful ship canal, with smooth banks, and deep water quite close to them, with no snags or bars to obstruct navigation.

Five miles below the head of the passes about 27 per cent. of the volume was discharged through Grand Bayou, which had a width of 300 feet, and a maximum depth of 30 feet.

Below Grand Bayou the channel is still uniform and regular, nearly 700 feet wide, but with only 35 feet depth, and an approximate section of 17 000 square feet.

The uniformity is preserved until the land's end is reached, at the mouth of the Pass, when the bank on the east side disappears from sight, and a reef, on which there is but about 3 feet of water, takes its place. A part of the volume of the Pass flows off to the eastward over this submerged bank. The western bank also commences to recede from land's end; the channel begins to shoal up, and more water escapes laterally as we go seaward.

About one mile and three-quarters from land's end, or "East Point," as denoted on the chart, the bar proper is reached, and extends for about 3 000 feet nearly level.

On this plateau there was about 9 feet of water, as a maximum depth, at average flood tide, or about 7½ feet at mean low water. The slope seaward commences at the outer limit of this plateau, and has a descent of about 1 foot in 60 feet.

The question as to what was the rate of bar, advanced before the jetties were commenced, cannot be definitely answered.

The authorities give 100 feet per annum, and it is probably not far from correct.

Third.—The General Principles on which the Construction of the Jetties was Based.

The formation and maintenance, for an indefinite time, of a deep and uniform channel through South Pass, gave a sufficient reason for following the example set by nature, and taught us that the artificial confinement of the ri arrent would, in a short time, produce the same results seaward of "East Point" that had been accomplished at any point between East Point and the head of the Pass, and that the two and a half milles immediately above land's end is no deeper or more regular in section than the two and a half miles from land's end to the outermost limit of the bar would be, if the same plan of bank formation was adopted in artificial construction that the river had used in the past centuries.

Again, as the crest of the bar was 2½ miles from deep water in the Pass, it was reasonable to assume that, if the banks were suddenly extended to the crest of the bar, the new bar, when formed, would be found 2½ miles from the present crest, for the same causes would produce the same effect.

Further, it was believed, that the time required by the Pass to build 2½ miles of banks in its natural condition, would be considerably lengthened under the new circumstances, and that, instead of 125 years, a greater time would elapse, for these reasons: *First,* we believe that the Gulf shore current of salt water, caused mainly by the northeast and east winds, and flowing generally westward along the face of the bar, would be accelerated by the building of the jetties out into it, and at right angles to it, and would carry far to the northward or eastward of the jetties the sedimentary matter thrown out by the fresh water currents. Also, *second,* that a strong and deep volume of fresh water, in place of the sluggish and shallow volume formerly flowing out, would have sufficient carrying and suspending power to throw the sediment

well out into the Gulf before being checked sufficiently to drop its load. Also, *third*, that this strong current, 30 feet deep, would itself perform the work of a dyke and compel the salt water current to go under it, and thus to erode the Gulf bottom over the whole area covered by the discharge from the jetties.

These results were more particularly looked for after the works were completed and the maximum channel fully formed; but during the progress of the work, and while the formative period of the channel continued, and while several million cubic yards of sediment scoured out of Pass and bar would be thrown out of the jetty mouth, in addition to the vast amount of sedimentary matter with which the river is charged we expected alternate scour and deposit both within the jetties and beyond them. We looked for marked and ugly irregularities that might give us trouble to control, guide and shape to uniformity.

The character of the material through which the channel was to be made was very variable; first clay, then sand, then a combination of the two, and through it the struggling current seemed to seek for a subterranean relief from its confinement.

Fourth.—The Detailed Plans of the Work.

In the location of the jetties several objects were aimed at.

First, to give them a direction parallel with the outflowing current, and at right angles to the shore currents along the face of the bar. *Second*, to give as wide an entrance for vessels as it was possible to obtain. *Third*, to remove the jetties themselves far enough from the channel to ensure their safety. The maximum channel to be obtained, according to the Act of Congress, is a depth of 30 feet and a width o 350 feet at that depth. The dimensions are remarkable, considering the section of the Pass itself, which generally has a much smaller section. It is still doubtful whether such a section, when obtained, can be maintained without danger to the jetties.

The location and alignment of the jetties can be seen best by an inspection of Chart No. XIV. The width between the guide piles on the side of the jetties is 1 000 feet. The clear width, between the jetties, is 930 feet. The lines drawn at right angles to the jetty lines are wingdams, provisional works intended to accomplish three objects: *first*, to compel the current to make the deep channel midway between the jetties; *second*, to induce deposits behind them and against the jetties; *third*, to hasten the erosion of the bar.

In order to hasten the confinement of the current and give an opportunity to work further out to sea with the mattress work, the first mile of the east jetty was built of sheet piling, after a foundation of mattresses had been laid in advance.

Two rows of square piles, 12″ by 12,″ were driven 12 feet apart, the piles in each row being 8 feet apart. The tops of these piles were sawed off to the same height, and two traveling drivers ran on them and drove the sheet piles against a waling timber, 6″ by 12″, which was bolted to the river row of piles. The sheet piles, which were 5″ by 12″ at the large end, and 3″ by 12″ at the small end, were driven about 15 feet into the ground, or until they were flush with the top of the waling timber, which was about level with "average flood tide." The sheet piles were drift-bolted to the waling timber.

Another provisional work was constructed along the first 3 000 feet of the west jetty. This consisted of plank aprons set on a foundation of mattresses, and held to the guide piles of the jetty by sheet piles driven in front of them.

All this provisional work was long ago supplemented by permanent mattress work. As the jetties are built of mattresses, it may be proper to describe them here.

A mattress is built of willows.

The willow found in this section of the country is not easily made into fascines; it is too stiff and crooked and branchy, and has none of the pliability of the osier willow used on dykes in Europe.

Most of the willows used on this work were obtained from an extensive swamp about 25 miles above Port Eads.

This vast willow swamp, threaded by numerous sloughs and bayous, was formed by deposits of sediment carried through a crevasse by the river.

This crevasse is called the "Jump," and occurred about 40 years ago, and at that time there was a bay with 5 or 6 feet of water where we now procure the willows.

There are probably 100 square miles of ground of a somewhat amphibious charater. We have already harvested from it about 100,000 cords of willows, and so rapid is the growth that we are now using material cut from the stumps of trees cut off in the early part of the work.

The stern wheel steamboat "Grafton" tows the empty barges to the

jump, takes them down into the bayou or "Passes," as they are called, for it is a little delta all by itself, leaves the barges at the camp of the willow contractor, takes away the loaded barges, and tows them to the jetties.

Willows have also been cut in considerable numbers from the river bank, as high up as the mouth of the Red River.

The mattresses are built on inclined timber ways; the inclination being 1 in 10. The timbers are 12" by 12", and extend back from the water's edge about 60 feet.

At one end they are a few inches below low tide, and at the other about 5 feet above the ground.

The timbers are parallel with each other, and spaced about 6 feet apart.

To avoid friction, a ribbon of 3" by 3" stuff is spiked to the timbers, and the upper side planed off to an edge.

The timbers and ribbons are well greased. The frame work of the mattress is made of yellow pine strips, 2½" by 6". They come in various lengths from 20' to 40'.

The mattresses are usually 100 feet long, and the strips are laid to this length by butting the ends together and fastening them by a lap of the same kind of material, spiked to the strip by 5-inch cut spikes.

These strips are laid at right angles to the timbers, and 5 feet apart from centre to centre; holes are bored with 1½" auger, 5 feet apart, and hickory pins, turned to fit the holes, are driven into them and secured on the under side of the strip by an oak wedge and 20-penny nails, toe-nailing the end of the pin to the strip.

If the mattress is to be 40 feet wide, there are 9 of these strips, and they are held in place by inch boards, tacked to them temporarily.

A barge of willows is placed alongside the ways, opposite the mattress frame, and workmen standing on the willows pass them out to those that stand on the frame, who place the willows at right angles to the strips between the pins to a depth of 6 inches; another layer of the same depth is placed on the first, and at right angles to it, and in the same way two more courses are laid, all at right angles to each other. Cross-binders are now cut the width of the mattress, and holes having been bored in them, so that they will fit the distance between the pins, they are driven down over them and pressed down by levers.

Wedges and nails are then driven in the top of the pins. The mat-

tress is now ready for launching. The tug comes alongside, moves the barge and pulls off the mattress by means of a strong bridle line, which has been built into the mattress.

The mattress floats about four inches out of water. The tug takes it in tow, and tows it to its place at the guide piling. A stone flat or barge is brought down and placed against the floating mattress. The stone is carried out and spread evenly over the mattress, until it sinks to its place. Another mattress is placed on the first, and another still, until the surface of the water is reached, when the last mattress is pulled on at high tide by a steam pile-driver engine.

The last course of willow work is built in place on the Jetty, by putting pins into the cross-binders of the top mattress, and then filling up with willows to the top of the pins, when cross-binders are put on as in a mattress. The whole work is then heavily loaded with stone. The foundation mattress is generally about 40 feet wide, and the last mattress 20 to 25 feet. It has not been found necessary, generally, to have any slope seaward, as the deposit back of the Jetties is so rapid that the sea side of the work is fully protected.

The last 600 feet or 700 feet of the sea ends of the Jetties needs a wide base and slope seaward, to protect it from the violence of the waves. This work is being done as fast as opportunity offers.

Fifth.—Instrumental and Hydrographic.

This subject, if entered into in detail, would require many pages and be of much interest ; but the space allowed will not permit a lengthy description of the methods employed by which, each month, a complete hydrographic survey, covering an area of nearly 13 000 000 square feet, and a mean depth of 20 feet, is made in four days, and plotted in another day. Necessity has been the mother of invention, and taught us many expedients, to not only insure accuracy, but speed, in surveying and plotting.

It has been the practice for two years, at least, to make a survey on the first of each month, very similar to the one shown on Chart XIV. From, these surveys records are kept, which will show eventually the whole history of the work. For a complete account of methods employed to make these extensive surveys in so short a time, I beg leave to refer to an interesting article by Mr. Max. E. Schmidt, Chief-Assistant Engineer, which recently appeared in the "Engineering News," May 30th, 1878.

In this connection, we refer to Chart XIV, which is made from the latest survey, and on which are drawn a few curves from the United States Coast Survey Map of 1875.

The plane of reference is "Average flood tide," as established by the Secretary of War, and all surveys are referred to this plane.

The tides are diurnal, and have an average range of about 14 inches, with an extreme range of 6 feet, which is the range between the highest and lowest waters ever known since the Jetties were commenced, caused by extraordinary local disturbances of winds and storms.

The principal points to call attention to on the chart are, *First:* The changes that have occurred between the Jetties, showing an increase of 15 feet in depth at the present shoalest point, with a much greater increase elsewhere. *Second:* The shoaling that has occurred on the sea side of the Jetties, especially at the West Jetty, where at some points there are but 2 feet of water, where originally, there were 16 feet. Also, laterally seaward of the first mile of the East Jetty, for where formerly there were three feet of water, the land now is a foot above the average tide, and covered with a thick growth of grass and reeds. *Third:* The shoaling against the Jetties on the river side, protecting them from the river currents.

Through the Jetties, however, though they are fast filling up among the willows and rock with sediment, there is still a considerable leakage. It is safe to say that at least 15 per cent. of the volume that passes East Point is lost through the Jetties before reaching the end at Station 118. The Jetties have generally been raised to the level of average flood tide, though from the natural subsidence of the material they are below that level at many points.

The principal work now being done is the loading of the Jetties heavily with rubble stone, especially near the ends of the Jetties, where they are exposed to wave action.

Experience during the provisional stage of the works, when, as yet only the core of the work has been built, proves to us conclusively, that the most exposed portions of the Jetties, when completed according to the plans designed, will be amply strong to resist any wave force that may come against them.

Sixth.—The Wing Dams.

They have been referred to already, but they have played so important a part in creating the channel that they should be described fur-

ther. They are temporary, generally, and can be removed whenever the object for which they are built is attained.

They are constructed by first driving a row of guide piles, 20 feet apart, against which are sunk foundation mattresses about 30 feet wide and 2 feet thick. These foundation mattresses connect at one end with the foundation mattresses of the Jetties, and at the other extend a short distance beyond the outer end of the intended wing dam. Across the river end of this foundation is sunk an apron mattress, about 70 feet long and 30 feet wide. A row of piles, 8 feet apart, are driven through the foundation mattress about 12 feet from the lower edge. A waling streak of 5″ by 9″ timber is bolted to them about 2 feet above average flood tide.

The wing dam mattresses are usually about 75 feet long, two to each wing dam, and are as wide as necessary to extend from about 2 feet above the waling timber to the foundation mattress. They are generally 2 feet thick, and many of them have a tight board bottom. They are raised to a vertical position by a steam pile driver and pinned close against the piles by driving piles about 20 feet apart and tieing them to the main row of piles.

While speaking of the wing dams we will describe and discuss certain phenomena which we believe to have been caused by these wing dams, and in the examination of which we have had the opportunity of investigating some of the geological questions relating to the bar.

Accompanying this paper are several plates, which will serve to illustrate the phenomena alluded to.

On plate XV are drawn portions of the jetty lines, and also certain wing dams or spur-dykes built out from the shore or the jetties at right angles generally to the current. The dotted lines drawn under the wing dams indicate that so much of them are intact, and that the remainder of the wing dam was either never finished or had fallen into decay.

Wing dams I and II, on the west side, are really the effective dykes, for those on the east side are built in shoal water of not over 10 or 12 feet depth, often much less, while Nos. I and II are, at their river ends, in 25 feet to 28 feet of water, and well out into the strong current.

Wing dams I and II were built in October, 1876, and the others shown on the sketch were built previously. As soon as the river rose in the spring of 1877 the effect of wing dams I and II was very marked. A

very rapid current was found to flow past them, and strong eddies under them. The whole channel, from Station 40 up to wing dam No. I, and even above it, commenced to improve at once.

The river commenced its annual rise about the last of March, and had nearly attained the flood stage of the year on the last of April. The readings on the Carrollton gauge, at dates affecting this subject, were as follows: April 30th, 10.60; May 25th, 11.00; June 6th, 11.00; July 5th, 10.60; August 1st, 7.10.

Opposite Station 50, the greatest depth, in April, was 33 feet. On the 25th of May it had increased to 75 feet, and an enlargement laterally had taken place. On the 5th of July, the basin had reached its maximum depth of that year of 95 feet, and had assumed the extraordinary proportions shown on Plate XV. Between July 5th and August 1st a slight deposit had taken place in the deepest portions, the river having declined considerably between these dates. Special attention is called to Plate XVI, on which are drawn surface float lines, and the slope of that portion of the water surface affecting the basin. The unusual velocity between Stations 30 and 36 is fully accounted for by an examination of the slope.

These slope observations were made on gauges set carefully by instrumental leveling and fastened to the piling of the East Jetty. They do not necessarily show the exact slope that existed midway in the channel between the wing dams.

If the slope of the central thread of the current below the head of the West Jetty could have been ascertained it would no doubt have shown that there was quite a fall from the middle of the pass towards the jetties; and if gauges set along the West Jetty could have been observed they would have shown a reversed slope, and would have given a reason for the strong current moving along the West Jetty flowing *up stream*. It will be noticed that there are no wing dams on the West Jetty from Station 38 to Station 71+30, a distance of more than 3 000 feet. The wing dams on the East Jetty, opposite this space, are in shoal water, and in a dilapidated condition, and none of them could have had any great effect upon the current.

The width of channel-way from Station 26 to 30 is not over 600 feet.

The width at Station 50 is about 900 feet.

With the data in our possession we may be able to find out some of the reasons that induced the river to excavate so great a basin in so short a time.

The float-lines on Plate XVI show that the outward moving current became narrower and narrower, like water forced through an orifice under pressure.

The least width of the current is found some distance *beyond* the greatest contraction. In some respects this action illustrates the principle of the "*Vena Contracta*" of Newton.

The particles of water in the centre of the stream flow straight out and at right angles to the edges of the orifice. The particles passing out at the sides of the vein converge, and the angle of convergence corresponds to the head of water against the edges of the orifice; or, in our case, against the protruding wing dams.

The wing dams are not water-tight by any means, and the loss through and over the first, at Station 26, is arrested by those at Station 30, and the second cause is given for still greater convergence of the particles; and so with the third set of wing dams at Station 35.

Thus the reasons for the convergence and for crowding the main volume into still narrower limits is easily seen.

This convergence continues until the wide open space at Station 45 is reached.

The contraction is, however, preserved to near Station 55, where it widens out rapidly to either side, flowing off on the side slopes previously mentioned; thus extraordinary eddies are induced, and they, in turn, pushed forward by the forces behind them, seek to enter or crowd against the main current, and thus from either side force the latter into still narrower limits.

The width of straight current at Station 48 may be assumed as 130 feet—sometimes greater, sometimes less. The line of demarcation between straight and eddy currents was usually very readily discerned by the eye. It often happened that in towing mattresses the eddy current would catch one end of the mattress and whirl it about tug and all.

We have the data for calculating approximately what the depth *should* be at Station 48.

Observations for the discharge of South Pass a short distance above the jetties, at the flood stage of the river for that year, gave 56 000 cubic feet per second, The volume passing at Station 48 was about 55 000 cubic feet per second, some loss having taken place through the jetties above this locality. The mean velocity of the straight current obtained from the surface velocity and using the co-efficient 0.89 is 4.45 feet per

second. The width being assumed as 130 feet, we have the elements of an equation for depth.

$$\text{Thus } (4.45 \times 130)\, x = 55\,000.$$
$$x = 95 \text{ feet.}$$

which was the maximum depth observed.

The reason for the deep excavations at the sides of the basin may be found in the existing eddy currents.

We are all aware, from our general experience, of the power of an eddy.

During the low river season the channel was somewhat rectified by wing dams built out from either jetty at Stations 45, 52 and 65.

During the time of this extraordinary scouring action the eddies induced an unusual and, as it were, a counter-balancing depositing action, and they threw off the material on the exterior of this almost circular basin much as a wheel throws off the mud by centrifugal force. The effect of all this irregular action on the channel below was injurious, and also exhibited a dangerous tendency towards undermining the West Jetty.

At the lower extremity of the very flat slope shown on Plate XVI. there was no tendency towards channel deepening, and the 750 000 cubic yards scoured from this great basin over-loaded the current in the lower reaches of the jetties, and produced a temporary tendency to shoaling the channel.

The effect of the flood river this spring showed the futility of attempting to rectify such extraordinary currents by wing dams built out from the jetties.

The deepest water is now at Station 45, where it is 108 feet.

Of late the ends of all wing dams above the West Jetty have been torn down back to the line of the jetty produced.

Now, that the cause of the formation of the basin is partly removed, we may look for a rectification of the channel,

With all the trouble that has been caused by this phenomenon it has yet produced a broad channel above and below the basin, and the tendency is now towards an elongation of the excavation.

This great basin afforded an opportunity of making examinations of the character of the material composing the bar in this locality.

An instrument weighing about 85 pounds was made, which had a sharp steel point for penetrating the material at the bottom, by allowing

it to drop from the launch. This steel point was fitted into a 2½ inch gas pipe about 8 inches long.

In the side of this point was an opening about 2 inches square with a projecting lip on the lower edge to catch the material when the sounder was drawn up. This short piece of gas pipe was screwed into another piece about 2 feet long. So that when the cavity was filled the point could be unscrewed from the longer piece and the material removed by a spoon. A mass of lead was run about the gas pipe to give it weight sufficient to strike the bottom with great force. To keep the point downward, while falling, a white pine post about 2½ feet long was fitted into the gas pipe and secured to it firmly by side straps of iron. A ring with a half inch rope attached was fastened in the end of the post, and the machine was dropped from the side of the steam launch, the rope running through a sheave set in a post about 5 feet above the rail of the launch.

The material brought from the different localities and depths was dried, then pounded up, if clay, and sprinkled on gummed paper. Several specimens are sent with this paper, the object of this examination being to ascertain the original character of the bar. A survey was made at the time of making those observations. The chart of this survey when compared with previous charts gave the data for making a sketch showing the line of demarcation between original material and any areas over which shoaling may have taken place since the jetties were commenced, and on which new deposits must have been made.

On this sketch, No. XVII, the points from which the specimens were taken are located and noted according to whether the material was clay, sand, mud or half clay and half sand by different kind of circles. A characteristic curve is also drawn at 26 feet depth, as the line between clay and sand seemed to be approximately near this depth. A record which was kept of the depth at which each kind of material was met by a dipper dredge working at Station 22, shows that the line of demarcation between sand and clay is at about 28 feet depth. Except on the crest of the bar there is no doubt that the limit of clay is about 26 to 28 feet, and that below that depth sand is generally found to an indefinite depth with occasional pockets of clay or of sand and clay mixed.

Seventh.—Interesting Phenomena.

For the purpose of offering facts for the study by those interested in the phenomena of the river and jetties, a chart No. XVIII. is given, which shows some of the active elements and their results. The in-

timaté relation between velocity, discharge, kind and ratio of sediment, scour and deposit are more clearly shown by this little sketch of curves than by any lengthy description or by voluminous tables. The figures from which some of those curves are made, are the result of many days and weeks of tedious work.

On this sketch is drawn the average position of each characteristic curve, whose history has been followed as closely as circumstances would permit.

They are the 20, 24, 30 and 40 feet curves seaward of the end of the jetties, and exhibit approximately the position of the outer face of the bar at each one of the dates recorded. The points for the curves are ascertained by means of ordinates spaced 50 feet apart. There are 24 of those ordinates, commencing on the line of the East Jetty produced and extending about 200 feet west of the West Jetty produced. They have a common initial line, from which the distances are measured on the ordinates to the point where they intersect the curve. The average distance on all the ordinates gives the point.

The curve of the river surface at Carrollton is also drawn. It may be noted here that extreme low water reads minus 1.62 on the gauge, and extreme high water reads plus 15.74 on the gauge. Ordinary low water reads about plus 2.0, and ordinary high water about plus 13.5.

The tides at low river cause a fluctuation of 8 inches on the gauge, but at high river or when the gauge reads 13.0 they become *nil.* This gauge has been read constantly for many years—and to its readings are referred many important river observations from Carrollton to the Gulf.

It was set in 1848 by Prof. C. G. Forshey, member of the Society, so that its zero should be at the level of mean tide of low river.

The sediment and sand curves are also drawn. They show the ratio of sediment to water by weight. This curve is taken from the records of observations made by Capt. Brown, whose careful and patient work is solving many of the important phenomena connected with the jetties. The specimens from which the record is made were taken from the South Pass at Port Eads.

There is also drawn a curve showing the total amount of excess of scour over deposit from East Point to 1 000 feet beyond the ends of the jetties—expressed in cubic yards.

A comparison of these curves shows some interesting results, the most important of which is, that considering the curve of the Carrollton

gauge the cause, all the other curves are results, and follow it very closely in point of height and time.

Thus the curves of the face of the bar are changed by the rise and decline in the river, by the scour between the jetties and by action of storm waves and sea currents; but the sand curve exerts an important influence also. Thus we notice, that on the first of August, 1877, the sand curve rises suddenly and to an unusual height. Immediately after this curve reached its highest point the 20, 24 and 30 feet curves extended out suddenly and to their greatest limit.

The curve of excess of scour does not represent all the material that has been removed, for there has been an extensive deposit along the river side of the jetties, extending out some distance from them. The whole amount of material moved, irrespective of deposit, is 5 252 566 cubic yards. The total of excess of scour over deposit to date of April 5, 1878, is 2 853 987 cubic yards, as shown on the curve.

The points on this curve are obtained by comparing surveys made at the beginning and end of each characteristic stage of the river at Carrollton, as nearly as those periods can be fixed to conform to the times of the regular monthly surveys, which are made on the first of each month, or as near that date as circumstances will permit. These characteristic stages of the river are: rising river, flood river, falling river and low river.

A skeleton chart is made on tracing paper from the two charts which show the condition of the channel at the beginning and end of the period —generally about three months in duration. This skeleton shows the areas of scour, deposit and no change, and is divided into three characteristic sections: the first from "East Point" to "Kipp Dam;" the second from "Kipp Dam" to the end of the jetties; the third from the end of the jetties to 1 000 feet outside. The width of the sections is the width between the jetties, except above Kipp Dam, where it extends from the East Jetty to the west shore. The difference in depths over these areas multiplied by the area gives prism of scour or deposit.

The result just worked out by comparing the survey of January 1, 1878, with that of April 5, 1878, is one of the most satisfactory ever found, and shows that the power for channel making by the jetties is by no means exhausted.

The river has been at two-thirds flood stage—the sediment curve is seen to be very prominent, and yet the skeleton shows an uninterrupted

scour from East Point to 1 000 feet outside the jetties. The only area on which deposit has occurred is near the jetties and away from the channel.

The prism removed from the channel during this period is 928 825 cubic yards, divided as follows on the sections numbered according to the above description.

Commencing above Kipp Dam.

Number I, 69 463 cubic yards.

Number II, 778 133 cubic yards.

Number III, 81 229 cubic yards.

The average deepening over the area scoured in section Number II is $8\frac{23}{100}$ feet. The scour in excess of shoaling over the whole area considered from East Point to 1 000 feet outside is 619 267 cubic yards. The excess of scour over deposit in the "1 000 feet outside" is 39 309 cubic yards, and as the area outside is 1 000 000 square feet, the average deepening is $1.\frac{06}{100}$ feet.

Eighth.—Changes in the Gulf bottom beyond the end of the Jetties.

The most important question, next to that of channel formation, is the condition existing seaward of the jetties. This question has become much more important than it would otherwise be, by the published statements and predictions, that have been made prior to and since the commencement of the work.

Preliminary to the discussion of this question, it will be conceded by all, that the greatest shoaling in front of the jetties would occur while they were being constructed and the channel was forming, for two reasons.

1st. During this time, now, of nearly three years' duration, there has been thrown out into the gulf nearly 3 000 000 cubic yards of heavy sedimentary matter in excess of all deposits.

2nd. The current force has been much weaker during the formative condition of the channel than it will be when the maximum depth is secured; for it is fair to presume that a current 30 feet deep will have much more carrying power than one 12 feet deep.

Now, what are the facts derived from two and one-half years' work? What is the condition of the Gulf bottom in front of the jetties, with a depth over the bar of about 23 feet? During the latter part of October of last year, a careful and minute survey was made to ascertain these

facts. The result is given on Chart XIX. and in the following tables, on which a comparison is made with the United States Coast Survey of 1875 previous to the commencement of the jetties.

Table of Comparison

Of the Quantities of Water in 37 Subdivisions of an area containing about 0.278 square miles, or 178.37 acres, immediately seaward of the end of

South Pass Jetties,

Between the dates of May, 1875, and October 1877, to accompany Comparative Chart—Plate XIX.

Number of Subdivision.	Area of Subdvision in sq. ft.	Mean loss in depth over Subdivision since May, 1875, in feet.	Mean gain in depth over Subdivision since May, 1875, in feet.	Quantity of Water lost in Subdivision since May, 1875, in cubic yds.	Quantity of Water gained in Subdivision since May, 1875, in cubic yds.	Number of Soundings in Subdivision.	
						May, 1875.	Oct. 1877.
1	500,000	....	4.1227	....	76347.	35.	223.
2	500,000	0.6909	....	12795.	....	26.	149.
3	500,000	....	1.4288	....	26459.	24.	85.
4	500,000	...	0.3682	....	6818.	19.	49.
5	500,000	0.8363	....	15488.	....	10.	35.
6	50,000	....	4.7833	....	8858.	5.	17.
7	100,000	0.3333	....	1234.	....	4.	19.
8	150,000	....	6.3208	....	35116.	7.	20.
9	200,000	2.8667	....	21234.	....	6.	21.
10	250,000	....	1.5750	....	14583.	8.	13.
11	50,000	0.0583	....	108.	....	7.	13.
12	100,000	....	1.3222	....	4897.	4.	14.
13	150,000	....	5.9833	....	33241.	5.	14.
14	200,000	1.8133	....	13432.	....	8.	13.
15	250,000	3.7083	....	34336.	....	3.	15.
16	100,000	....	0.3444	....	1276.	10.	23.
17	100,000	....	1.4944	....	5535.	5.	13.
18	200,000	....	4.1733	....	30913.	6.	18.
19	250,000	....	1.6972	....	15715.	10.	20.
20	100,000	....	3.8167	....	14136.	7.	13.
21	100,000	....	3.1222	....	11564.	6.	10.
22	200,000	....	3.0533	....	22617.	14.	10.
23	250,000	1.4944	....	13837.	....	8.	13.
24	100,000	....	0.0611	....	226.	4.	14.
25	200,000	....	0.2767	....	2049.	10.	20.
26	250,000	....	2.8055	....	25977.	10.	16.
27	60,000	....	2.2667	....	5037.	2.	15.
28	100,000	....	2,7722	....	10267.	4.	12.
29	200,000	....	2.3966	....	17753.	7.	15.
30	250,000	....	2.0861	....	19316.	11.	19.
31	60,000	....	0.0417	....	92.	2.	7.
32	125,000	2.9095	....	13470.	....	7.	19.
33	250,000	....	1.3028	....	12063.	7.	15.
34	250,000	....	5.9055	....	54681.	14.	22.
35	125,000	....	2.0286	....	9392.	10.	11.
36	250,000	....	2.4194	....	22402.	8.	17.
37	250,000	2.7889	....	25,823.	....	4.	19.

Key to Combinations.

Combination	"A"	contains	subdivisions	1-5	inclusive.
"	"B"	"	"	1-15	"
"	"C"	"	"	1-23	"
"	"D"	"	"	1-31	"
"	"E"	"	"	1-37	"

Letter of Combination.	Area of Combination in sq. ft.	Mean *loss* in Depth on Combination since May '75, in ft.	Mean *gain* in Depth on Combination since May '75, in ft.	Quantity of Water *lost* in Combination since May, 1875, in cub. yds.	Quantity of Water *gained* in Combination since May, 1875, in cub. yds.	Number of Soundings in Combination.	
						May, 1875.	Oct. 1877.
A	2,500,000	....	0.8785	....	81,341	114	541
B	4,000,000	....	0.7269	....	107,690	171	700
C	5,300,000	....	0.9965	....	195,609	237	820
D	6,520,000	....	1.1443	....	276.328	287	928
E	7,770,000	....	1.1661	....	335,572	337	1,031

Area of scour..............4.311.000 square feet.
" shoaling...........3.459.000 "

Total area.................7.770.000 "

Average increase in depth over area scoured,

$$\frac{335.572 \text{ cub. yds.}}{4.311.000 \text{ sq. ft.}} = 2.102 \text{ feet.}$$

The accompanying map and the foregoing tables explain themselves.

The method employed in the calculations may be open to the charge of interpolation of soundings; but any other method was impossible, owing to the paucity of the Coast Survey Soundings in many of the subdivisions.

The interpolation is made with all possible accuracy, and the number of soundings in each division is given in the tables, that anyone may judge of the possibility of error.

The *fact* of the deepening seaward of the jetties is established by this survey, and it is fully coroborated by a survey of May, 1876, which was compared with the same Coast Survey chart used in the above calculations.

The surveys of Captain Brown, which are far more extensive, attest the accuracy of the result given in the tables. In a comparison of two of his own surveys, one of June, 1876, and the other of June, 1877, he shows that there has been an average deepening of 1 foot and $3\frac{7}{10}$ inches over an area of 542 acres in front of the jetties, the boundary lines of the area on each side radiating from the ends of the jetties, and extending seaward of them one mile, with a width at the outer limit of one mile and a half.

We offer the following reasons for this deepening:

1st. The jetties are built out into and at right angles to a salt water current, which at certain seasons of the year and under certain conditions of the winds, flows along the face of the bar.

This current may be due entirely to the winds, or to other causes in part. It is not always in the same direction; generally it flows to the westward, but often to the eastward, and sometimes there is no perceptible current either way. During the fall and winter and early spring months the winds prevail from the northeast and east, and the current to the westward is often well marked and strong.

Thus the jetties are dykes built into a river of salt water and at right angles to its currents. This causes a "race" in front of the jetties, extending its influence some distance beyond them.

2d. Over the old bar there was a sluggish outward river current about eight feet deep; over the new bar there has been a current with an average depth of twenty feet for the last two years. The velocity and power of this current is much greater than that formerly existing.

This strong volume of fresh water cannot be thrust aside at once, nor, on the other hand, can the volume of salt water be dammed up by it. The result therefore of a meeting at right angles of these two forces, is a depression of the salt water current into the very soft gulf bottom, and a consequent scour and removal of the material to restore the sectional area encroached upon by the new and deeper fresh water current. As a corroboration of these views, attention is called to the areas of scour and deposit on the chart, the former being shown by the unshaded portions and the latter by the shaded portions. Well defined channels of scour can be traced across the whole area and at right angles to the discharge of fresh water from the jetties.

These facts, so fully corroborated by independent surveys, made at different times by different parties, with the additional fact taken from

them, viz.: that nearly all the contours in front of the jetties from twenty feet to eighty feet, or as far as any examinations have been carried with sufficient detail for comparison have receded, show conclusively that the whole outer slope of the South Pass bar has advanced *landward* instead of *seaward*.

How much the jetties will need to be extended annually, or even when an extension will be necessary, no one can predict in the face of these indisputable facts.

This we do know, and we emphasize and restate and insist upon it, that under more unfavorable circumstances than can ever recur again, the jetties have caused a scour, instead of a deposit, in front of them.

In a late official report of Maj. C. W. Howell, U. S. A., he offers the opinion that this deepening is due to influences similar to those operating in crevasses of the river bank.

Let us for a moment compare the conditions existing at the end of the jetties and those at Cubit's crevasse.

This crevasse occurred about fifteen years ago. It is three miles above the head of the passes, on the east bank of the river.

The fall between the surface of the water in the river at flood stage and the adjoining bay is from three to four feet.

The almost immediate result of the crevasse was the formation of an extraordinary crater about 180 feet deep, or about 130 feet deeper than the river near by.

A very short distance from this great depth there was not more than six feet of water. This condition has existed to this date. I am credibly informed that the launch of an engineering party, drawing three-and-a-half feet, was hard aground at the bow, while over the stern the lead went down a perpendicular precipice over 100 feet deep. Here we have a great volume of water forced under the pressure of four feet head against the bank of the river; the result is a tremendous vertical eddy that makes and maintains an extraordinary excavation. The fresh water volume pushes to one side the salt water and sweeps over the shoal ground. Where this flow, some distance from the river, is checked, the bay is filled up by a deposition of the sediment, and grasses and willows are already growing in abundance.

At the end of the jetties, the head of water is not more than three inches at the maximum. Instead of a river bank and shoals to strike against, the fresh water current flowing out of the jetties moves out

gently over a stratum of salt water. The stratum of fresh water becomes thinner and the salt water deeper as we go from the end of the jetties seaward.

Now, much of the deepening, shown on the chart, has taken place where we know by observation that there is a depth of fresh water at flood stage of the river of say twelve feet, moving gently and smoothly seaward, without boils and eddies, on a stratum of salt water forty feet thick.

Can it be imagined even that this thin layer of fresh water is disturbing and throwing into commotion in its gentle flow a layer of denser and heavier salt water under it ?

Again, how account for the deepening that occurs during low river when there is *no* head of water and the salt water fills the jetty channel and the Pass and the tides flow in and out almost without obstruction ?

We know that most of the deepening, or a large part of it, occurred during low river, and, without any doubt, from the effect of the littoral current ; for the current itself can be plainly distinguished, and the deepening occurs at the same time.*

Ninth,—THE HEAD OF THE PASSES.

With all the peculiar and interesting phenomena connected with the jetties, and the engineering difficulties connected with them, there was nothing at the mouth of the Pass that presented the difficulties that have been met at the head of the Passes.

In order that a full knowledge may be had of the conditions existing there, a map of the Mississippi River and Passes at the point under consideration is given, Plate XX.

The U. S. Coast Survey Map of May, 1875, has been used for comparison, and the fifteen feet, twenty feet, twenty-six feet and thirty feet curves are drawn on the accompanying map which was made from a survey of March, 1878.

The South Pass is a bayou compared with the two large Passes.

The depth into it was only about fifteen feet, while nearly thirty feet could be carried into the other two Passes.

In order to deepen the bar, partially blocking the channel into South Pass, it was necessary to obtain erosive power in some way. This could only be done by an increase of velocity, which could be obtained only by giving the current flowing into South Pass a greater slope, and this

* See page 158.

could only be the result of a greater head of water above the Pass in the river.

This head of water was obtained by the works constructed and shown on the map; but a head of water could not be raised above the head of South Pass without also raising it above the other passes, and thus making side slopes into them, down which, for the time being, some of the volume rightfully belonging to South Pass flowed into Southwest Pass and Pass à l'Outre.

However the works were designed, as shown on the map on the supposition that the South Pass would not allow itself to be largely robbed of its volume, and that while a portion of it might, for a while seek the other passes it would return whenever there was an unobstructed entrance into South Pass.

There is no doubt that the process of channel making at the jetties was delayed many months by the partial loss of the volume belonging to South Pass.

The volume that flowed into South Pass formerly spread over a wide expanse and the lines of the neutral axes were as follows: that between South Pass and Pass à l'Outre intercepted East Dyke about 600 feet below "Cluster;" that between South Pass and Southwest Pass intercepted "T-head Dam 2" about 300 feet below its upper terminus.

The work first constructed was "East Dyke." This was built in the winter of 1875 and the spring of 1876.

It was intended to intercept a portion of the volume flowing into Pass à l'Outre and deflect it into South Pass.

The order of the construction of this dyke, which was built solid of mattresses laid horizontal, was as follows:

Work was commenced at the upper end in December, 1875, at low river, and the foundation course was laid down stream; then the second couse was laid in the same way. At about the time of the completion of this course, the spring rise of the river came and almost immediately shoaled the channel near the dyke, so that the depth was about the same as that on the mattresses. A new plan was then adopted by constructing the dyke to the surface of the water from the lower end, working up stream, and completing it as we went.

It was thought that as the dyke, as previously constructed, had acted like a submerged dam, inducing deposit above it, it would become a real deflecting dyke, if built to the surface, working up stream. The current

did seem to make desperate efforts to break through the deposit made in front of that portion earlier constructed, but it was unable to do so, for the depositing tendency overbalanced the scouring power. The eastern channel shoaled up to eight or ten feet.

The plan of the works, as shown on the map, was then designed and carried into execution, and a change of base was made from Pass à l'Outre to South West Pass.

"East Dyke" was used as a base to work from, and the confinement of the volume in the lower line of the western channel was the ultimate object.

"Dam No. I," built in a similar manner to the wing dams described previously, was first constructed in the fall of 1876; then a T head across the west end of it extending up to "New Cluster." A dam was thrown across the eastern channel between the head of the island and "East Dyke."

This latter work was of too temporary a nature, and was undermined and much of it washed out.

A more substantial and permanent structure was afterwards built to replace it, and known as "Island Dam."

The "Dam II." was also built in the fall and winter of 1876, and a "T head" was built parallel to the opposite "T head Dam I." The opening between these two T heads was 800 feet. During the winter of that year and the early spring of 1877 a channel, about 20 feet deep and 50 feet wide, was dredged through the shoal lying between the T heads.

As soon as the river rose in the spring, this channel quickly widened and deepened, and has continued to improve ever since.

After the channel had been formed, it was found that the current impinged too severely upon "T head Dam 2," and that the shoal lying under "T head Dam 1" was too extensive. In order to remedy those evils, the "T dam I" was torn down between "New Cluster" and "Dam I." Below "Dam I," nothing but a foundation course of mattresses was built.

The "T head Dam 2" was built in a permanent and substantial manner. An extension was added to it in the spring of 1877, and constitutes that portion that curves to the eastward.

Gauging simultaneously the three Passes, it was ascertained that there had been loss of volume by South Pass. This was in the summer of 1876.

In the fall of that year a sill of mattresses was laid across the Southwest Pass, connecting "T Dam 2" with the west shore of that pass.

In the spring of 1877 a similar sill was laid across Pass à l'Outre, connecting the upper end of "East Dyke" with the east bank of that pass.

The object of these sills was to prevent any further loss of volume, and to induce more water to flow into South Pass.

As these sills were important and somewhat peculiar in construction, and as the difficulties were considerable in laying them, we will describe them briefly.

The mattresses were constructed at the Jump, about 12 miles above the works; they were towed down the river by a stern-wheel steamboat, and tied up to anchorages built some distance above the works.

The tug took them from this position and towed them astern to the sill.

About 175 feet above the lower line of the sill, which was made of mattresses, 70 feet long, 25 to 40 feet wide, and 2 feet thick, anchorages were built about 150 feet apart. They were constructed of three piles, driven in the form of a triangle, about 8 feet apart. These piles supported a plank platform, and were held securely together by 5" by 9" timbers bolted to them, and on which the planks were spiked. In order to make an angle of about 45 degrees between the level of the platform, which was about 2 feet above the water, and the bed of the river above the platform, two piles were driven about 30 feet above the platform, and bolted together, after which a ¾" chain was slipped over them and let fall to the base of the piles; the running end was made fast to one of the platform piles and drawn taut with the engine of the steam pile-driver.

Ranges were put up to show the lower line of the sill, which was 70 feet wide, the length of the mattresses, and they were then—two or three, and sometimes four at a time—placed in position; each one as it was dropped down by the tug and made fast by long head lines to the platforms, was hauled to its place beside the others or against side guide piles by the driver. When all that were to be sunk at one time had been placed in position, side by side, and pulled close together, so that the brush was jammed, the pile-driver swung around to the opposite side of the mattresses and drove two, sometimes three, guide piles close into the bushy edge of the outer mattress. The mattresses were all lashed securely together and to the piles, so that in sinking they would not break apart. One, and sometimes two, stone flats, carrying about 50 cubic yards of stone, were placed above and against the upper edge of the mattresses.

The stone was carried off the flats first to the lower edge of the mattresses and evenly distributed over it, sinking it from the lower end to just the surface of the water. When the whole fleet of mattresses, sometimes 160 feet in width, or 4 mattresses, 40 feet wide and 70 feet long, was covered with water, the men commenced rolling the stone off of the flats on to the upper edge of the mattresses. By this means, by slacking gradually the lines holding the flats to the anchorages, they dropped down over the sinking mattresses, the men meanwhile throwing off the stone as rapidly as possible. Soundings were taken on the mattresses as they sank, so that they could be put down level on the bottom.

When they were found to lie smooth on the bed of the river, they were well loaded, and the lines, all except the lashings, were taken off. As many of these mattresses were sunken in 30 feet of water, with a current sometimes from 3 to 4 miles per hour, with the piles and anchorages swaying back and forth, with mattress lines so taut that it seemed as though they would snap asunder, the difficulty of the work can be imagined.

Neither of these sills has ever been disturbed by the currents. Their continuance was necessary to success, and all possible pains were taken to secure it.

The effects of all these dykes. dams and sills is already very marked.

1st. A deep scour through the entrance channel, extending to the narrow channel between the island and the west shore.

2d. Over the whole area included between "East Dyke" and "T head Dam 1," where formerly there were 15 feet of water, there has been a general shoaling. so that now there are only about 2 feet of water. This shoaling has extended below "Island Dam" and above "Dam I," far up into the river.

On the west side, there has been considerable shoaling above "Dam II."

3d. Changes have occurred, and are occurring, which are very favorable for the channel.

Above the Southwest Pass sills, extending to the upper limits of the survey shown on the map, and from the west shore half way out across the Pass, there has been an average shoaling of about 1½ feet during the last 12 months. The 30 and 26 feet curves have advanced down stream about 700 feet during the last year, immediately above the South Pass channel, and in the line of current flowing into it.

We may reasonably conclude, that the mattress sills are having some effect upon the regimen at the head of the Passes.

Although the obstruction is slight, it must yet exert an influence.

During certain conditions of the wind, the "ripple" or "break" of these sills can be seen entirely across the Passes.

With a bed so easily moved, the volume of water now exerting itself to "jump" these sills will slowly but surely seek the less obstructed entrance of South Pass, so that we may look for a still deeper channel into South Pass as a result of these sills; at any rate, we will recover the volume which may have been lost.

If these sills should be raised, especially the one across Southwest Pass, the head of water above them would be increased, and a side slope would be found to exist towards South Pass channel, on which the water would flow into the latter.

Whether the problem is fully solved or not, the indications for complete success at the head of the Passes are very favorable.

There are many items and even subjects of interest that have been omitted necessarily from a paper of this kind and extent.

The details of the construction of the work closing Grand Bayou; the method by which the slopes of the Pass and river have been ascertained; a description of the powerful hydraulic dredge boat *G. W. R. Bayley;* the history of the construction of the jetties, with the quantities of materials used; and the commercial advantages that have already resulted from opening the river's mouth to deep draught vessels.

When the whole work is finished, and final success attained, there might be written a personal history of the enterprise, of the most thrilling interest, in which might be related the discouragements, temporary failures, and obstacles of all kinds, which have required and found a heroism, and a patience, and a persistence, and a sublime faith on the the part of two men (one an honored member of our Society), who, as engineer and contractor, have carried the work through to success against obstacles and through darkness and trouble, that long ago would have appalled or utterly discouraged any but the bravest spirits.

FOOT NOTE.—The report of Captain M. R. Brown, U. S. Inspecting Officer for the year ending June 30th, 1878, now being published, shows an average increase of depth of 1 8-10 feet during the last twelve months over the area of 1¼ square miles beyond the jetties' ends.

AMERICAN SOCIETY OF CIVIL ENGINEERS.

INSTITUTED 1852.

TRANSACTIONS.

NOTE.—This Society is not responsible, as a body, for the facts and opinions advanced in any of its publications.

(Vol. VII.—June, 1878.)

DISCUSSIONS ON

THE SOUTH PASS JETTIES.

By CHARLES W. HOWELL, E. L. CORTHELL, C. SHALER SMITH. and J. FOSTER FLAGG.

CHARLES W. HOWELL.—Through the courtesy of Mr. E. L. Corthell, member of the Society, I have been favored with a manuscript copy of that part of his paper on "The South Pass Jetties" which treats of the deepening in the Gulf, immediately in front of the jetties.

I am thus enabled to offer, at the present time, a discussion of that portion of his paper.

About one year ago, if I am not mistaken, it was announced that, over a selected area, immediately in front of the South Pass Jetties, there had been discovered a deepening in the Gulf averaging 4½ feet.

Shortly after this announcement, Capt. M. R. Brown, inspector of the work, officially reported an average deepening of one foot three and seven-tenths inches, but in making his calculation covered a greater area than that before covered. Objection was made to his introduction into his calculation of certain sub-areas (called side areas), over which there

had evidently been great shoaling, but which were, it was contended, not sufficiently well covered by soundings given on the coast survey chart used as the basis of comparison.

At the time it appeared very strange to me that the deepening reported should have occurred, and judging from the several years of experience in sounding off the bars of the several Passes of the Mississippi, as reported to me by my assistants employed upon the work, I was disposed to think that the several results were more due to inaccurate soundings than to actual scour.

Afterward I suggested (see my last annual report) that scour *might* have been caused, over a *limited* area, by eddies, similar to those observed in crevasses, and no doubt to be found in all cases where water, under head, is suddenly released from confinement and projected against a denser body, either stationary or in adverse motion.

In view of the discovery announced in the paper before us, that, over the area of which the paper treats, there is nearly always a strong current flowing out of the South Pass, and frequently a very considerable current flowing at right angles to it, I am not disposed to press my suggestion nor abandon it, but find some reason for return to my original opinion.

Under the conditions stated it would, no doubt, be a very difficult matter, if not a hopeless undertaking, to obtain accurate soundings immediately in front of the jetties.

Giving due weight to selection of areas, the variety of results so far presented may suggest correctness of this opinion.

The author of the paper under discussion frankly admits interpolation of soundings to supply deficiency, no doubt, in the coast survey chart on which he bases his comparison.

While fully assured that this interpolation has been as fairly made as any one could make it, it is yet desirable that we should be informed as to the method employed, and also that the interpolated soundings should be so designated upon the chart (No. XIX.) accompanying the paper. The importance of this may appear from the great regularity with which the soundings have been plotted, and from a knowledge of the very considerable and sudden irregularities found in the outer slopes of the bars of other passes, where a few feet difference horizontally has frequently shown several feet difference in depth.

I have looked upon interpolation in such cases (as a method of com-

parison) as one to be avoided if possible, and have considered the selection of limited areas as apt to lead to erroneous conclusions. I will, however, offer a calculation based on the figures given in the large central rectangle (chart XIX) enclosed at the sides by the lines running outward from the jetty ends and covering the axis of discharge along which it would be reasonable to expect the greatest deepening.

My calculation results as follows :

Average deepening $\frac{574}{1000}$ ft.

It is this portion that is best covered by the coast survey soundings, (if I remember rightly), and these soundings were made before the construction of the jetties had increased the difficulty of obtaining accurate soundings over this area. It was to be expected that with currents of considerable velocity passing over this area at right angles to each other, soundings made with the greatest care would indicate an average deepening, inasmuch as the Gulf current, in passing under the axis of the river current, should apparently be given its greatest scouring effect, and also aid in deflecting the sounding line from a perpendicular.

On examining Chart XIX. one is first struck with, what may not be inaptly called, the topographical features of the gulf bottom over this area.

There will be noted three valleys, with suspicion of a fourth, and three well defined mountain (?) ranges (pardon the hyperbole), with reasonable expectation of a fourth, if the chart had been carried a little further out.

The axis of each valley and range is approximately at right angles to the axis of the jetty channel.

The valleys are undoubtedly valleys of erosion and the ranges due to deposit or upheaval, as will appear from the chart, and from the following table compiled from it :

From End of Jetties Out.

Valleys.		Ridges	
Mean Average Increase of Depth.	Maximum Increase.	Mean Upheaval.	Maximum Upheaval.
No. 1.			
7.498 feet.	21.2 feet,	9.782 feet.	24.8 feet,
No. 2.			
11.187 feet.	24.1 feet.	6.520 feet.	22. feet.
No. 3.			
5.341 feet.	13.6 feet.	4.935 feet.	9.5 feet.
Part of No. 4.			
2.666 feet.	6.2 feet.		

I assume the ridges to be due to upheaval for two reasons :

1st. Because it does not appear reasonable to expect deposit in such position and arranged in such order.

2d. Because at other passes I find, from years of survey and observation that the same phenomena are presented, and that the ridges are due to upheaval of the mud-lump stratum, and form what I have called the nucleus of bar formation.

One notable fact developed by this apparently reasonable selection of area is this, viz., that in order to obtain the average stated in the paper it was found necessary to include certain side areas, affected no doubt by the horizontal eddies, and to exclude nearly all beyond.

Taking the central area alone, and then comparing it with the total, leads to the conclusion that the axis of discharge of the pass is represented on the gulf bottom by a ridge, and that ranges 1, 2, 3, &c., are but spurs of this ridge.

This would appear very singular if we did not know the tendency toward bifurcation, which all the passes of the Mississippi, except the South Pass, heretofore have shown within the time covered by authentic record.

It is also noticeable that the maximum of deepening and of upheaval decrease as we proceed from the jetty ends gulfward.

This is precisely what has been noted in crevasses during their early stages, and what has, in their case, been ascribed to vertical eddies caused by water, under head, tumbling over one obstruction to butt against another, and over that to meet a third, and so on.

The heads of Cubitt's crevasse and of the Bonnét Carré crevasse are now about equi-distant from the level of the Gulf. During high water in the river their fall is about as follows, in the order named : 3 to 4 feet and 20 feet, yet the depths of first crevasse hole are about as follows : 123 feet and 53 feet, which would indicate that depth of erosion is more dependent on date of delta formation than on head of water. Hence we are led to believe that a head of only 3 or 4 inches in the jetties may create quite deep holes, or valleys, in the bar formation in their front, which is of the newest formation. However, whether the average deepening (?) immediately in front of the South Pass jetties be wholly or partly due to crevasse effect, or whether it be wholly or partly due to gulf currents, is a matter of secondary importance.

Mr. Corthell emphasizes the statement : "That under more unfavorable circumstances than can ever occur again, the jetties have caused a scour instead of a deposit in front of them."

The opinion as to more unfavorable circumstances not being likely to present themselves, does not appear to me as well founded, yet if it should prove not to be, jetty application at the mouth of the Mississippi will probably be abandoned in the course of a few years.

So important a matter is well worth consideration.

In the first place, we learn from the several published reports of the inspecting officer, that for several hundred feet from the projected outer ends of the jetties it was found such a difficult matter to secure foundation on the newly made portion of the bar (where even the guide piles driven gradually went down under their own weight and action of the waves), the maintenance of these portions, at full height, was not persisted in. It was, apparently, discovered that such maintenance would be a very expensive task.

Now let us assume that ridges No. 1 and No. 2 continue to rise at the rate shown in our table, we must believe extension of the jetties will be called for at an early date. Not only completion of the troublesome few hundred feet cited, but extensions over valleys No. 1 and No. 2.

Of course such extension would not be impossible, but it would evidently be very costly, and similar extensions might not afterward be undertaken.

I cannot believe, as Mr. Corthell does, that the greatest difficulties have been overcome. I look for these in the near future.

The difficulty does not alone lie in this very important one of frequent extension into the Gulf over a newly made sedimentary deposit of great thickness and little sustaining power as a foundation, but it also lies in the predicted and observed shoaling of the whole body of the Pass; in the great uncertainties which must attend any attempt to force an increased volume of water through the Pass, and in the upstream growth of the bar at the head of the Passes.

E. L. Corthell.—Major Howell has reciprocated the courtesy which he alludes to, and has kindly furnished me a copy of his remarks to be read in the discussion of my paper on the "South Pass Jetties."

As a considerable portion of his remarks and much of his argument is consumed in attempting to show, that the results which I speak of, as facts, are illusions brought about by inaccurate soundings, I will say:

1st. It is reasonable to suppose that the soundings taken by one corps of professionals is as reliable as those of another, but when one is engaged in a special investigation, and the other in general surveys, the former is generally supposed to work to a nicer degree of accuracy. So in the surveys under discussion, I give the preference to Capt. Brown's party rather than to Major Howell's.

2d. It is an error to compare the difficulties under which Capt. Brown labored with those that the Coast Survey party met, for the simple reason that Capt. Brown compared two of *his own* surveys, and made no comparison with the Coast Survey.

3d. The survey of Capt. Brown cannot be compared with the one that is alluded to, as disclosing a deepening of 4½ feet—since the former covers in its comparison only one year, while the latter covers two years.

4th. The survey made in October, 1877, which forms the basis of comparison with the results of the Coast Survey of 1875, a chart of which is given, was made under the most favorable circumstances that could possibly exist.

The difficulty (?) which Major Howell speaks of, resulting from cross currents, did not exist, for it was made at the low water season, and there was no river discharge to interfere with accuracy. There was a straight current across the mouth of the jetties, and at right angles to them, with a velocity of about 1½ miles per hour. The soundings made on lines run *against* the current, *with* the current, and *across* the current, checked closely with each other.

5th. Capt. Brown states that accurate soundings can be made to a depth of 100 feet. The deepest sounding on the chart in question is not much over 50 feet.

The difficulties which Major. Howell's party has met with, exist in deep soundings, from 100 feet to 300 feet or deeper. This is the first intimation we have ever had that our work made immediately in front of the jetties is necessarily inaccurate on account of cross currents.

Granting for a moment, that the difficulties do exist. on account of new and strong under currents flowing across the mouth of the jetties, may we not reason, that a current, that would have such a marked effect on a lead line, would move the soft material of which the outer slope of the bar is formed.

Major Howell regrets that we have not given more fully the details of the interpolation used on the chart XIX, and also given the original soundings themselves.

It may be stated, that *all* the soundings are interpolated, the object being to obtain comparative depths at each corner of each square of 100 feet to make the calculation for the prism more accurate.

The original soundings were not put down, as it would cause great confusion on the chart, but the number of soundings on each subdivision is given in the table accompanying.

An attempt was made to obtain the mean depth by averaging the original soundings, but it was found to be a "mean depth" only in name, especially on subdivision No. I, one of the most important, for the Coast Survey soundings of small depths, over this area, were far the most numerous, and consequently a calculation obtained by averaging the depths would have given a mean depth much too small, and an increase of water prism much too great.

From the careful study of the subject, and of the most accurate methods, I am certain that the results are obtained in the most accurate manner possible under the circumstances.

The selection of the areas for the calculation was made entirely with a view of covering, as nearly as possible, the discharge of the river volume, and *not* in any case with a view, as Major Howell intimates, of including areas over which there had been a deepening.

The interesting description and analysis of Major Howell, illustrating his theory of mud lump formation, is instructive on that point, but we fail to see how it bears on the subject under discussion, for the chart, and

especially the two models, which so well illustrate this subject, show very plainly that the "mountains" have been brought low, and the valleys made deeper by the erosive action of both salt and fresh water currents. The statement made in my paper, that all this has been done under more unfavorable circumstances, than can ever occur again, is not disproved, and the acknowledgment by Major Howell, that the strong fresh water volume thrown out by the jetties has caused a deepening by crevasse (?) action, gives us reason to expect that the same causes operating in the future, with greater force and under more favorable circumstances will produce still greater deepening, and that the reason which existed for withdrawing landward the ends of the jetties, will continue to exist to an indefinite time. That reason was not the subsidence of the ends of the jetties, but because it was entirely unnecessary to build the jetties as far seaward as was contemplated originally.

C. Shaler Smith.—The gist of Major Howell's remarks appears to be contained in the three difficulties which he points out, to wit, insecure foundations for future extension of the jetties, shoaling of the body of the pass, and the upstream growth of the bar at the head of passes.

Concerning these I would suggest that an embankment can be supported on any deposit of the Mississippi river, provided it is given a mattress base of sufficient width; next, that by a proper contraction of the other two passes by means of mattress sills, the water in the South Pass can be made to move at a speed sufficient to prevent shoaling, and lastly, that a modification of the same system of operation may be used so as to effectually control the direction and shape of the upstream growth of the "Head of Passes" bar.

J. Foster Flagg.—The river Magdalena, in South America, has some interest in this connection, as having recently engineered for itself a channel through the bar at its mouth, after having had its navigation obstructed thereby for centuries.

This river flows due north into the Carribbean Sea, and, although draining a much smaller area, it resembles the Mississippi very much in its general characteristics, especially for the last five or six hundred miles of its course, which is in a very flat, alluvial region, covered with dense tropical forests; its water is heavily charged with sediment, and it presents the same features of caving banks, rapidly changing channels, formation of cut-offs, new islands magically springing up in its midst, and large districts inundated in time of high water.

The town of Barranquilla, the principal port of the country, is located on the left bank of the river, about eight miles above its mouth. According to old Spanish charts, and even according to quite recent ones, the island of Gomez, which forms the right bank of the mouth (Bocà de Ceniza) had a tongue of land (shown in accompanying sketch) three miles in length, running in a westerly direction across the mouth, and coveréd with high sand hills and woods, so that the Carribbean Sea was entirely shut out from view to one on the river until fairly passing out at its mouth. The water was very shallow over the bar, and no sea-going vessel thought of attempting an entrance.

As Carthagena lost its commercial importance after the Spanish yoke was thrown off, Barranquilla, from being a mere fishing village gradually became the principal port of export and import of the commerce of the country, the great internal highway for which is the Magdalena. As ships were unable to enter the river, they anchored in the bay of Savanilla, which then had from five to seven fathoms of water, discharging at the village of the same name into lighters, which transferred the cargo by the way of the small channel (Cano), on the south side of the Isla Verde, to Barranquilla.

Gradually this harbor silted up—it now having not over ten feet of water—the Cano also became unnavigable, and vessels were compelled to lie some distance off from Selgar, to and from which all merchandise was lightered, and conveyed over a railroad built from thence to Barranquilla by a German company. At the same time the channel on the easterly side of the island of Gomez, through which communication is had with the port of Santa Marta on the Caribbean Sea to the eastward, was becoming shallower, and the tongue of land was, unnoticed, melting away.

Now, this tongue has entirely disappeared (see dotted line on map), the river is straight, and a clear view of the sea can be had from the river for several miles above its mouth. This tongue, reinforced, doubtless, by the sediment of the river, has apparently been carried by prevailing currents around the Isle Verde, filling up the bay of Savanilla, and the increased force of the river current has cut for itself a good navigable channel through the bar to the deep water outside.

Some eight or ten years ago a sailing vessel of small tonnage was driven into the mouth by stress of weather and anchored off Barranquilla, much to the astonishment of the inhabitants. In March, 1873,

the notorious steamer Virginius (shortly after captured, under United States colors, by the Spaniards, and taken into Cuba) was lying at Gelgar; it suffering from oxidation of the hull, Captain Williams obtained permission of the Colombian Government to take her through the mouth of the Magdalena into fresh water. He was accompanied by Capt. Jaime de Pocaterra, both in entering and in returning some two months later. The Virginius only drew about eight feet of water, but according to Pocaterra, they found, by sounding, a minimum depth of four fathoms, and a width of channel through the bar of some 350 feet. Above the bar the river has a depth of nine or ten fathoms.

Recently, I see by the daily papers, the steamers of the Atlas line, drawing about 18 feet, have entered the river and discharged their freight close to Barranquilla, thus proving, practically, the practicability of the channel for vessels of large draft.

AMERICAN SOCIETY OF CIVIL ENGINEERS.

TRANSACTIONS.

(Vol. VII.—June, 1878.)

Addition to Paper No. CLX.

The author desires to add to Paper No. CLX: "On the Cause of the Maximum Velocity of Water flowing in open channels being below the surface," by James B. Francis, published in Transactions, Vol. VII., May, 1878, the following sentence:

Currents of water have the power of carrying in suspension earthy matters, which, if the water was at rest, would sink to the bottom; the amount which can thus be carried bearing some relation to the velocity. From the observations and experiments in this paper, it would appear that this power is due to the constant movement of water from the bottom towards the surface.